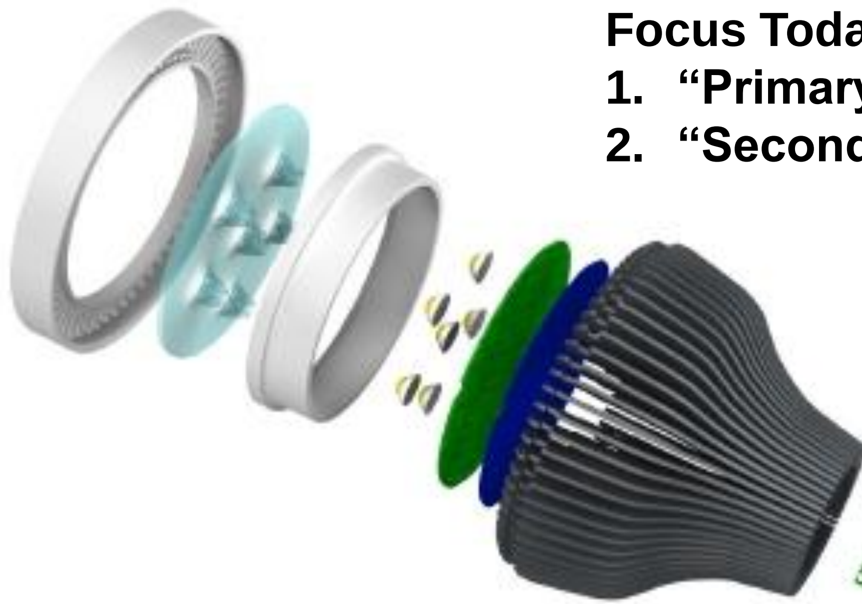
Advanced Silicone Materials for LED Lighting

DOE SSL R&D Workshop

Joel McDonald
Dow Corning Corporation
January 28th, 2015

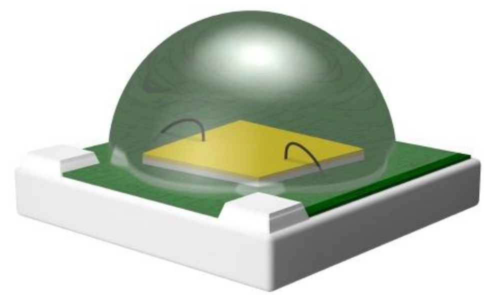
Dow Corning Products for SSL

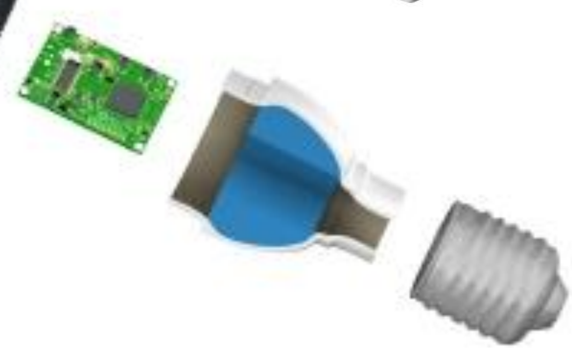
Our Goal: Provide customers with material solutions that enable their performance and design objectives.



Focus Today:

1. **"Primary Optics"** → LED Encapsulant
2. **"Secondary Optics"** → Luminaires Lenses





3. **Packaging and Assembly**
   - Adhesives & Thermal Management
   - Dielectric Gels and Pottants

Observed LED Trends: Primary Optics

1. Emerging LED architectures → new encapsulant formats
2. Customers will evaluate new materials & processes **IF** there is a clear cost or performance benefit.
3. Customers consider methyl silicone encapsulants (refractive index = 1.4) → would prefer high performing phenyl materials (refractive index = 1.5+) **IF** they can pass reliability testing.

Our Response: Dow Corning has developed new solid silicone encapsulants that are expected to meet emerging requirements but require modified LED packaging processes to realize benefits.

Solid Encapsulant / Hot Melt: Key Concept

Viscoelastic Solid
Phosphor Dispersion
(sheet or film)

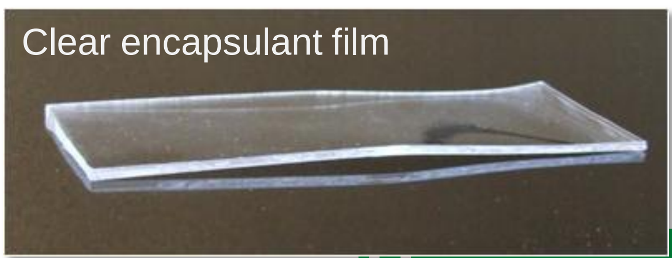
→

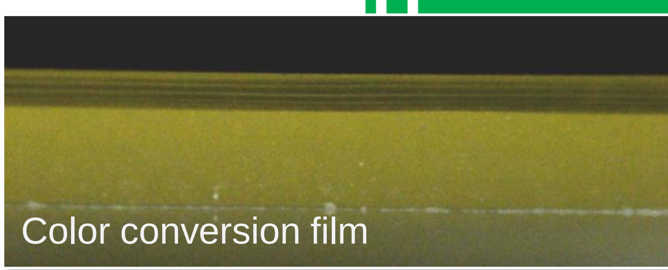
Viscous melt
Process
(laminate or mold)

→

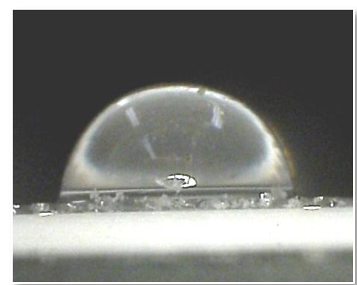
Thermoset
Fully Cured
(encapsulation complete)

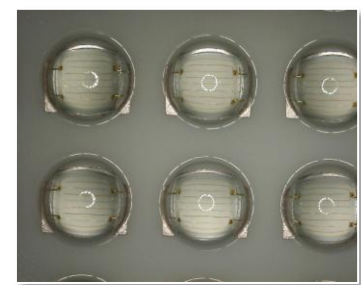
T<60°C | 100°C<T<140°C | T>150°C

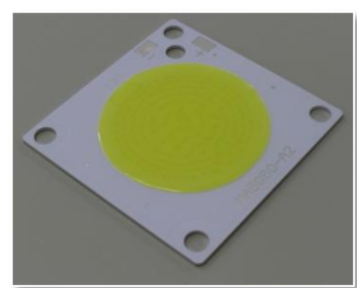


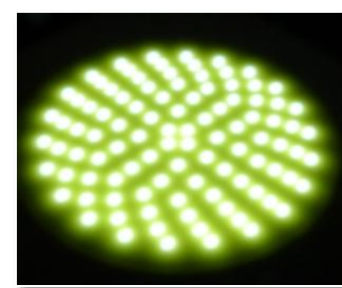


Mold or Laminate & Cure

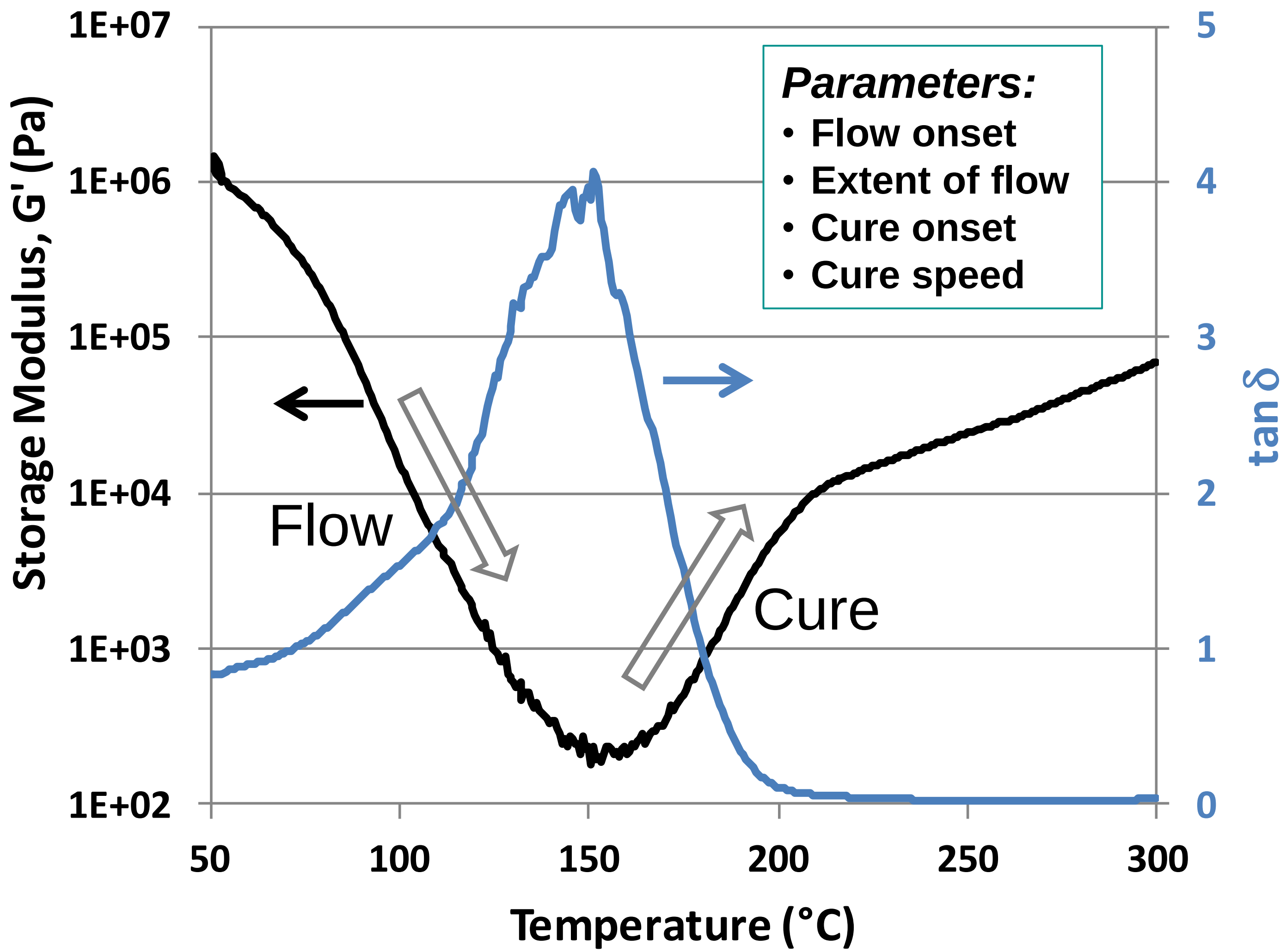








Reactive Hot Melt: Cure Kinetics

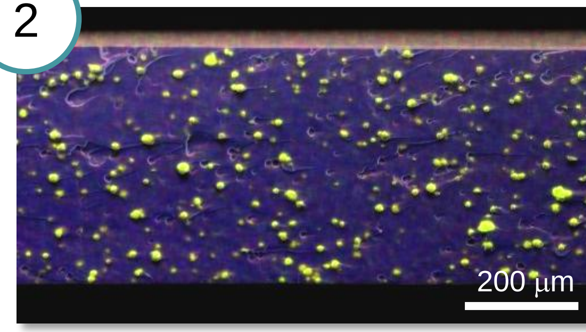


Dow Corning Solid Silicone Encapsulant:

Solid Encapsulant Films:

1. Coating process 50-400 μm
2. Uniform phosphor dispersion
3. No evidence for phosphor settling

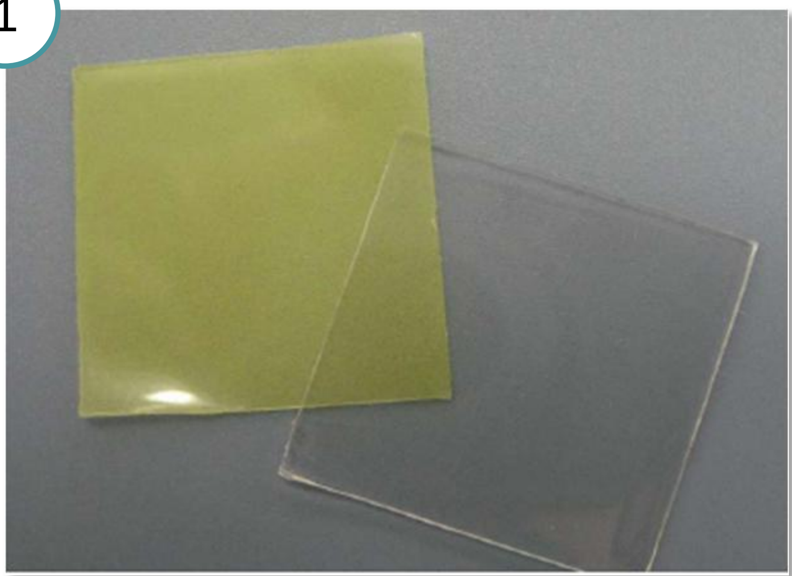
2



Si
O
Al
C
SE

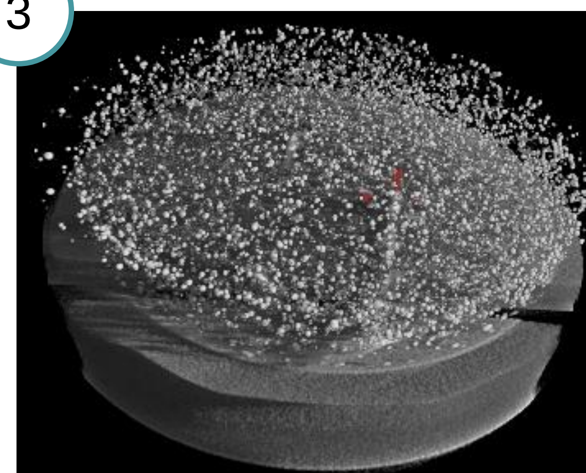
~400 micron Ce:YAG infused film
(SEM cross-section)

1



Photograph of phosphor loaded and clear sheet.

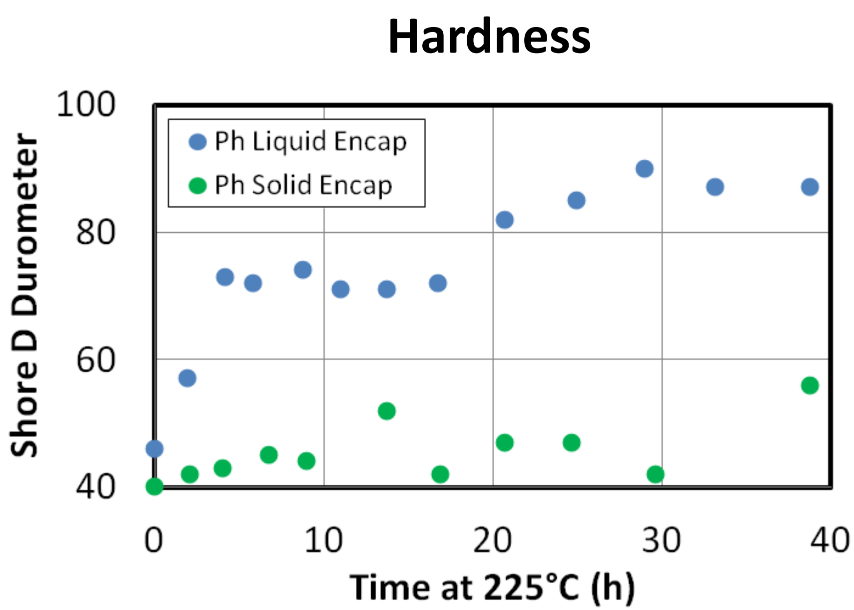
3

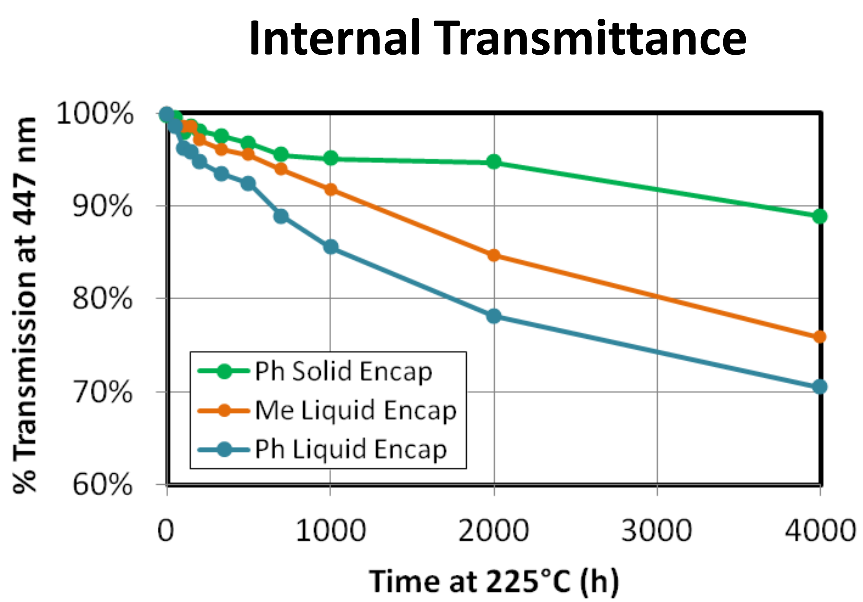


X-Ray CT image

Thermal Stability: Aging at 225°C

	Tensile Strength, MPa			Elongation at Break, %		
	Initial	1,000h, 225°C	4,000h, 225°C	Initial	1,000h, 225°C	4,000h, 225°C
Me Liquid Encapsulant	5.9	1.2	Too brittle	390	24	Too brittle
Ph Liquid Encapsulant	4.10	Too brittle	Too brittle	100	Too brittle	Too brittle
Ph Solid Encapsulant	4.1	4.5	7.5	65	10.4	6.1





Key Result: Reduce Embrittlement

Key Result: Maintain Transmission

Refractive Index: Options and Limitations

1. **Current method:** Add phenyl to ↑ refractive index (vs. methyl only)
   A. Current Materials:
      - Phenyl Silicones: n = 1.52-1.56 vs. wavelength from 400-700nm
      - Methyl Silicones: n = 1.41-1.43 vs. wavelength from 400-700nm

   B. Future Materials:
      - Silicones can be extended to n ≅ 1.60 using polymer modification

   C. Limitations:
      - Excessive Phenyl → decreased stability
      - Law of diminishing returns → an upper limit

2. **Emerging Methods:** additives and modifications to phenyl silicones
   A. High refractive index **nano-fillers**; nano titania, nano zirconia
      - Demonstrated refractive index increase: 1.5 →1.63 @ 550nm (TiO_2) [1]

   B. High refractive index **atomic modification**: hetero metallic siloxanes
      - Demonstrated refractive index increase: 1.55 → 1.58 [2]

3. **Challenges:** stability, stability, stability
   - Maintain optical and mechanical properties under aging conditions

[1] Jui-Hsiung Huang, et al., *Preparation and characterization of high refractive index silicone/TiO2 nanocomposites for LED encapsulants. Journal of the Taiwan Institute of Chemical Engineers, 2015.* ***46(0): p. 168-175.***
[2] Yong Ho Kim, et al., *Sol–Gel Derived Transparent Zirconium-Phenyl Siloxane Hybrid for Robust High Refractive Index LED Encapsulant. ACS Applied Materials & Interfaces, 2014.* ***6(5): p. 3115-3121.***

Observed LED Trends: Secondary Optics

1. Emerging SSL applications → highly stable materials that support aesthetic and efficacy requirements.
2. Emerging luminaire designs → new production processes
3. Standards Definition → more efficient material R&D [1,2]
   A. LED standards/guidelines well defined (LM-79,80,84, IES TM-21, etc.)
   B. Electronics and flammability standards well defined (UL, CE, NEMA)
   C. Global effort to define standards for Luminaires (LED Systems Reliability Consort)
      - Customers currently apply both LED standards, and internal tests.
      - Future standards will combine optical, electrical, and lifetime/failure metrics.

Our Response: Dow Corning has developed a portfolio of silicone products with the goal of enabling customers to achieve performance and design objectives at the luminaire level.

[1] Strategies Unlimited, LED Luminaires 2013, Marketing Report.it/
[3] US DOE SSL R&D Report 2014 : http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2014_web.pdf

Silicone Secondary Optics for SSL: Reflector

Silicone based **white reflective materials**

1. Injection Moldable silicone white reflector: MS-2002
   - High reflectance (92% at 3mm), co-moldable with clear MS-1002 products
2. Spray Coating silicone white reflector: CI-2001.
   - Applied to metal (Al, steel) or plastic luminaire assembly components
   - Increase surface reflectivity → increased efficiency for light fixtures

CI-2001 SUMMARY

FEATURES

- Glossy finishing, White reflective
- Cures to tough, resilient, abrasion resistant surface
- Low VOC

BENEFITS

- Helps improve light output and efficiency
- Easy to apply and can be repaired
- Better heat and yellowing resistance than some plastics and organic coatings/paints

APPLICATION METHODS

- Spray, Brush, Flow, Dip

Property	Units	Value
1-Part moisture cure coating		
Reflectivity	@3mil	94%
	@5mil	96%
Viscosity	cP	5150
Color	L*(D65)	98.7
% Solids	%	50
Tack Free Time	min.	10

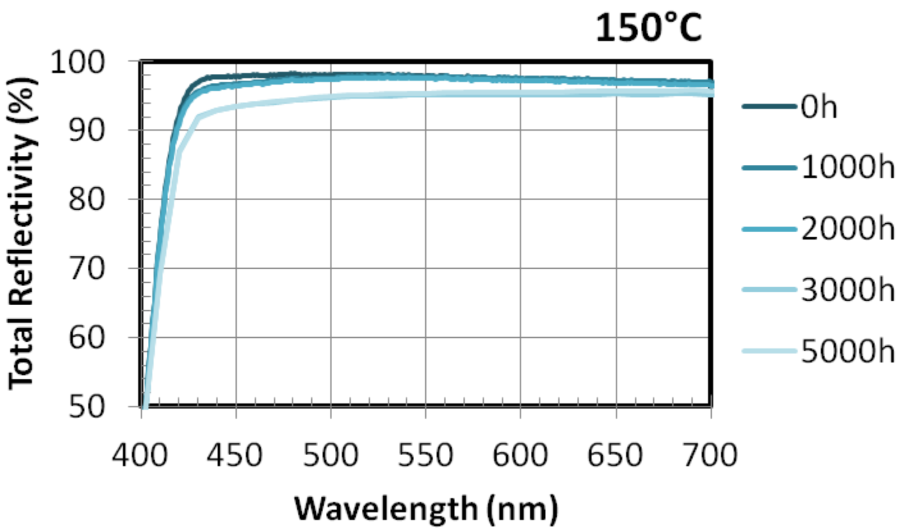
Thermal Stability: Aging at 150°C and 200°C

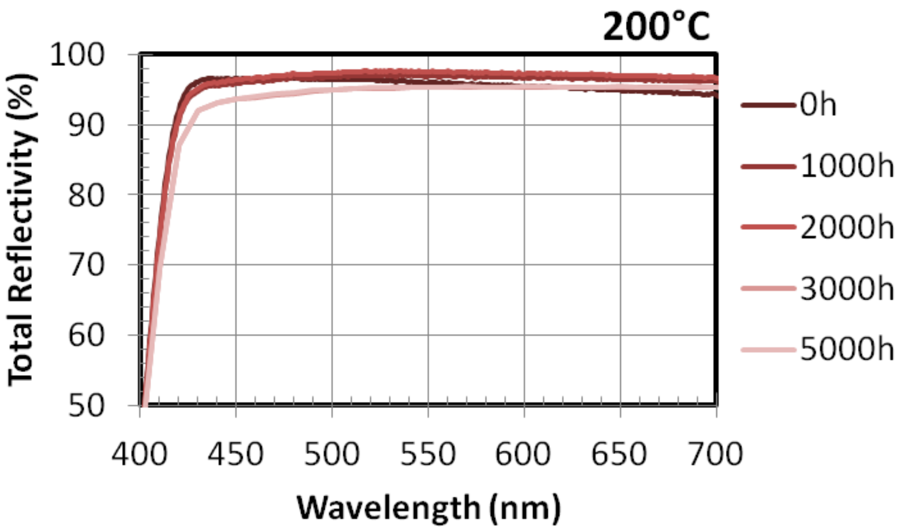
Product Details: CI-2001 white reflective coating

Sample Details: Draw down films on Al, 15 mil drawdown wet thickness

Aging Details: Samples heat aged at 150°C and 200°C for up to 5000 hrs.

Test Details: Reflectivity values from Konica-Minolta CM-5

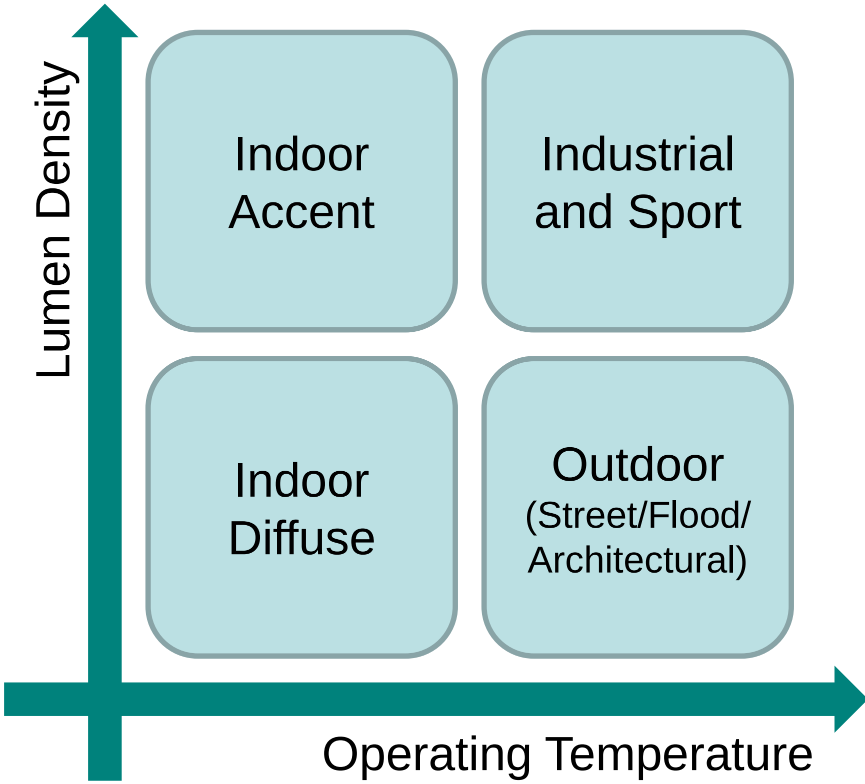




Key Point: Reflectivity maintained under thermal aging conditions.

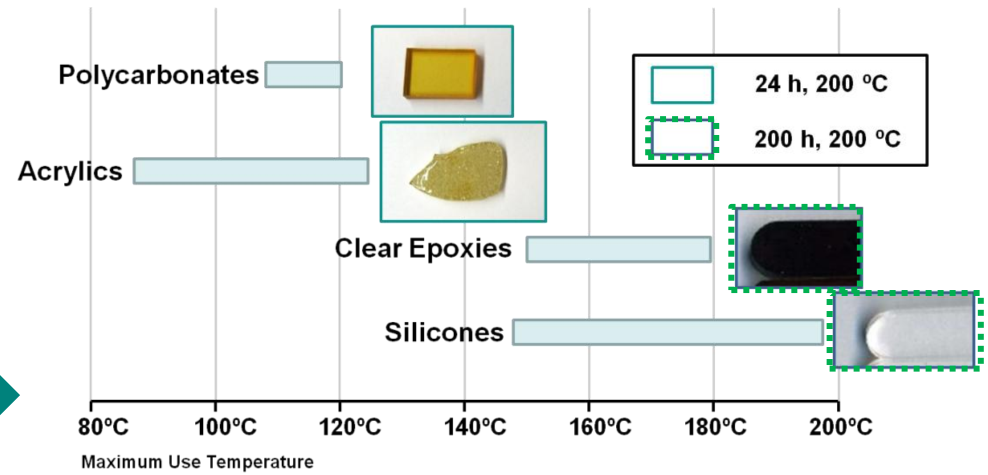
Silicone Secondary Optics for SSL: Challenges

- Different segments have different operating conditions, but **all** segments must maintain color temperature and lumen output over the lifetime of the luminaire.



DOE's multi-year program plan addresses:
- A.8.1 Light Quality Research
- B.6.3 System Reliability and Lifetime

Key question: What tests most effectively link luminaire performance to optical materials.



Materials of construction must tolerate high temperatures and lumen flux

Advanced Silicone Materials for LED Lighting
Summary and Potential R&D Areas

1. New Applications → New Requirements → New Products
   - Dow Corning has developed a solid silicone encapsulant that delivers thermal stability compared with conventional silicones.
   - **R&D Area:** phosphor integration at the macro, micro, and nano-level
2. What level of refractive index can be achieved with silicones?
   - Stable performance from phenyl silicones anticipated at n=1.6
   - **R&D Area:** Alternative routes under exploration; a question of stability
3. Silicones for Secondary Optics: Design Flexibility & Performance
   - Dow Corning has developed a portfolio with the goal of enabling our customer's expectations for performance and function.
   - **R&D Area:** continue to define/consolidate testing at luminaire level

Thank you